Physics of Flares from Black Hole Microquasar V4641 Sgr in the Radio, Optical and X-rays

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Abstract. We present a disk instability model for unusually short, but intense and chaotic, flares of a few days observed in a black hole microquasar V4641 Sgr= SAX J1819.3-2525, a multiple component relativistic jet source. To reproduce the observed short duration of the flare, a ring-like, truncated Keplerian disk is required. We discuss causes of such a truncated accretion disk based on the disk instability model, and implication to short-duration flare events observed in other microquasars and fast X-ray transients.

BLACK HOLE MICROQUASAR V4641 SAGITTARII = SAX J1819.3-2525

Black hole microquasar V4641 Sgr was discovered in February 1999 in quiescence by BeppoSAX and RXTE/All Sky Monitor, and designated as SAX J1819.3-2525 [1][2]. On September 1999 its bright and super-Eddington, but unusually brief outburst was observed in the radio, optical and X-rays up to 100keV [3][4][5]. Accompanied superluminal radio jet identifies the source as a microquasar [3]. Optical spectroscopic observations show that V4641 Sgr is a high mass black hole binary with the black hole and companion masses of ~ 9.6 and $\sim 6.5\ M_{\odot}$, respectively, with an orbital period of 2.81 days [6].

In Figure 1, we present the 1999 February−September X-ray and optical light curves of V4641 Sgr. In the top and middle panels, X-ray observations are displayed: publicly available data of RXTE/PCA (filled and open triangles), RXTE/ASM [4] (×) and BeppoSAX (open square) [5]. The optical light curve is also presented (a dotted line) in the top panel for a comparison. In the bottom panel, the visual observations (open circle) adopted from VSNET[5] and from [7], and CCD data (filled circle) [4] are presented.

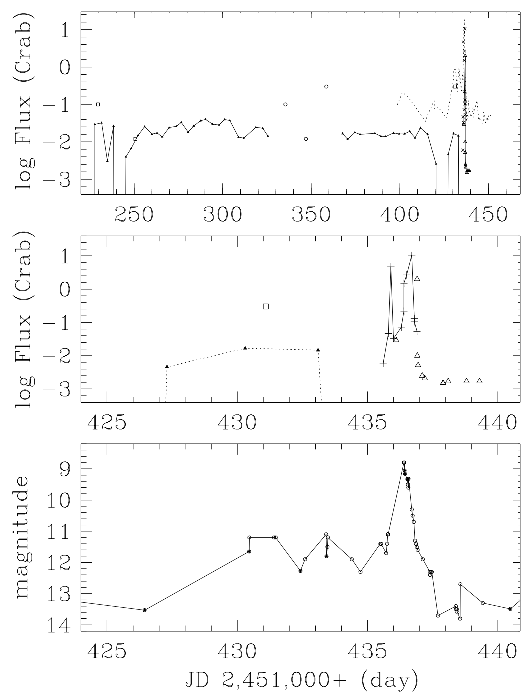

FIGURE 1. X-ray and optical light curves of V4641 Sgr observed in February−September 1999.

In the optical, the precursor flaring activities for a month, and more intense and rapid oscillation-like behavior for a week were observed prior to a day-long main flare [4]. In X-rays, the peak was delayed by about a half day from the optical maximum [4][8]. In May 2002, V4641 Sgr displayed another, more complex outburst with a strong correlation to X-rays [9]. The transient, therefore, repeated its outburst activity with an interval

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of $\sim$ two and a half years. In this paper, we focus only on the 1999 outburst.

RING-LIKE KEPLERIAN ACCRETION DISK IN V4641 SGR

The outburst of V4641 Sgr is characterized by a very short outburst duration, about a day for the main flare, with the peak luminosity close to the Eddington limit. That is, the total mass which is accreted in one outburst is also small, compared with the case of typical black hole X-ray novae.

The most successful model to explain the X-ray nova outbursts is the so-called "disk instability" model, originally proposed for dwarf-nova outbursts [10][11][12]. The essence of the model is that, in quiescences, accreted matter from a companion star is accumulated in outer disk portions and, when the disk temperature goes up over the critical limit for ionization, $\sim 10^4$ K for hydrogen, the heating wave propagates inward and the disk emits radiation. To explain a very short outburst, it is required based on the disk instability model that the thermally unstable region should be small so that the accreted mass for an outburst is small. The outburst rise time scale, $\tau_{\rm r}$, is given by, according to the disk instability model (e.g., [11]):

$$\tau_{\rm r} \approx \frac{\Delta r}{\alpha c_{\rm s}}, \tag{1}$$

where $\Delta r = r_o - r_{in}$ with the outer and inner disk radii, r_o and r_{in}, respectively, α is the viscosity parameter, and C_s is the sound speed. To get a day time scale for $\tau_{\rm r}$, the radial disk size should be on the order of 10^{10} cm, while $r_o \leq 10^{11}$ cm. The decay time scale, $\tau_{\rm d}$, is, on the other hand, given by the viscous diffusion time scale of the ionized disk portions. It is on the order of hundred days for the disk parameters relevant to black hole X-ray novae. In such a truncated disk, however, $\tau_{\rm d} \sim$ a day or two because of $\Delta r \ll r_o$ (see [11]). The rise and decay time scales of $\sim$ a day can be, therefore, achieved only with such a truncated Keplerian disk. The detailed time scale analysis will appear in [13].

TIME-DEPENDENT DISK MODEL: NUMERICAL RESULTS

The radial extent of the disk, Δr, we adopted is $\sim 2\times10^{10}$ with $r_o \sim 10^{10.9}$ cm for 9 $M_\odot$ black hole. Mass transfer rate from the companion star is $\sim 5\times10^{17}$ g/s. Viscosity parameters in hot and cool states are $10^{-0.3}$ and $10^{-1.0}$, respectively.

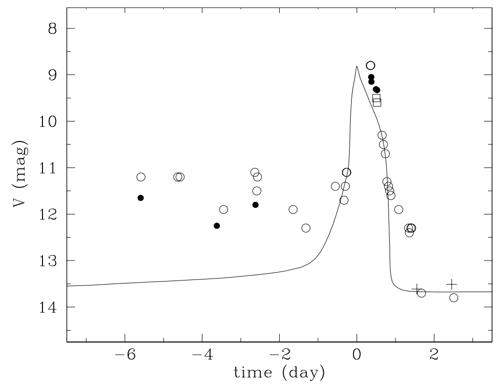

FIGURE 2. The calculated optical light curve (with the solid line), together with the observed data presented in Figure 1.

In Figure 2, we present an example of computed light curve based on the disk instability model, together with the observed optical data in Figure 1. The time-dependent disk instability model is consistent with the observed light curve for the 1999 major outburst of $\geq$ a day. A week-long precursor activity observed prior to the major outburst will be discussed in detail in [14]. The detailed numerical results will be presented in [13][14].

DISCUSSION

A day time scale outburst observed in the Galactic black hole microquasar V4641 Sgr is much shorter than durations of a few hundred days in typical black hole X-ray novae. We demonstrate that such a short outburst can be explained based on the disk instability model only if the radius of the inner edge of the Keplerian thermal disk is relatively large, only a factor of few smaller than the outer edge of the disk. Based on the disk instability model, the time-dependent computation can reproduce the rapid outburst observed in V4641 Sgr. By the onset of the disk instability in the outer ring, an enhanced mass accretion flow propagates to the inner region in which the disk temperature is much hotter, thermally stable and, presumably, advection-dominated (see [15] and references therein). We will present more discussion on the inner hot disk region in [13][14].

There are a few black hole candidates observed with short-duration flares such as CI Cam (XTE J0421+560) [16] and XTE J1739-302 [17]. In addition, there are a few unidentified transients with rapid flare events observed in X-rays, the so-called "fast X-ray transients" (e.g., [18][19]). Some of these transient events could be caused by such a ring-like disk geometry we suggest here. More discussion on this issue can be found in [13].

ACKNOWLEDGMENTS

We are grateful to David Smith for discussion, helpful comments and, in particular, for providing up-to-date information of XTE J1739-302. We thank to many amateur observers for supplying their visual and CCD estimates via Variable Star Network (VSNET), and to Matoko Uemura and Taichi Kato for providing us the VSNET and CCD data. We also thank to Mikhail Revnitsev for kindly sending us his X-ray data of V4641 Sgr. This work was supported by Strategic National R&D Program M1-0222-00-0005-02B0600-00400 from the Ministry of Science and Technology, Republic of Korea.

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